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Evolution of Magnetic Fields around a Kerr Black Hole

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**abstract** The evolution of magnetic fields frozen to a perfectly conducting plasma fluid around a Kerr black hole is investigated. We focus on the plunging region between the black hole horizon and the marginally stable circular orbit in the equatorial plane, where the centrifugal force is unable to stably balance the gravitational force. Adopting the kinematic approximation where the dynamical effects of magnetic fields on the fluid motion are ignored, we exactly solve Maxwell's equations with the assumptions that the geodesic motion of the fluid is stationary and axisymmetric, the magnetic field has only radial and azimuthal components and depends only on time and radial coordinates. We show that the stationary state of the magnetic field in the plunging region is uniquely determined by the boundary conditions at the marginally stable circular orbit. If the magnetic field at the marginally stable circular orbit is in a stationary state, the magnetic field in the plunging region will quickly settle into a stationary state if it is not so initially, in a time determined by the dynamical time scale in the plunging region. The radial component of the magnetic field at the marginally stable circular orbit is more important than the toroidal component in determining the structure and evolution of the magnetic field in the plunging region. Even if at the marginally stable circular orbit the toroidal component is zero, in the plunging region a toroidal component is quickly generated from the radial component by the shear motion of the fluid. Finally, we discuss the dynamical effects of magnetic fields on the motion of the fluid in the plunging region. We show that the dynamical effects of magnetic fields are unimportant in the plunging region if they are negligible on the marginally stable circular orbit. This supports the “no-torque inner boundary condition” of thin disks, contrary to the claim in the recent literature.